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**STRENGTH PROPERTIES OF REINFORCED PLASTIC
LAMINATES AT ELEVATED TEMPERATURES**
(EPOXY RESIN ERSB-0111 and 181-S-HTS GLASS FABRIC)

KENNETH H. BOLLER

U. S. DEPARTMENT OF AGRICULTURE

TECHNICAL REPORT AFML-TR-65-165

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AIR FORCE MATERIALS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
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FOREWORD

This report was prepared by the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, Madison, Wis. Work here reported was sponsored by the Air Force Materials Laboratory under USAF DO 33(657)63-358. This contract is carried under Project No. 7381, "Materials Application," Task No. 738106, "Materials Information Development, Collection and Processing." It was administered under the direction of the AF Materials Laboratory, Research and Technology Division, Mr. T. J. Reinhart, Jr., project engineer.

Data on the epoxy laminates are based on work that was done between January 1964 and January 1965.

The material tested may not have been developed or intended by the manufacturer for the conditions to which it was subjected. Performance is therefore not necessarily indicative of its utility under less stringent conditions or for other applications.

Manuscript released by author March 1965 for publication as an RTD Technical Report.

This technical report has been reviewed and is approved.



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ABSTRACT

This report is one of a series that presents strength properties of materials designed to endure elevated temperatures. Strength properties and strength-exposure curves are given for an epoxy resin laminate, made by Union Carbide Plastics Company, with ERSB-0111 resin in conjunction with 181-S-HTS glass fabric. The data show the effects of temperature between 80° and 1,000° F., and exposure periods between 0.05 and 1,000 hours on the individual strength properties. The magnitude of the various effects may be judged separately. In general, the data show that all mechanical strengths, except tension at 0°, decrease uniformly with increases in temperatures of short duration. The tensile strength remained relatively high until a critical exposure was reached and then displayed erratic characteristics. Other mechanical strengths above 400° F. decreased with increased exposure but peaked at about 100 hours.

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I. INTRODUCTION

The development of ever faster flight vehicles and the resulting increases in their operating temperatures require expansion of knowledge concerning the strength properties of the new structural materials to be used. Reinforced plastic laminates are being used or considered in many structural components of flight vehicles, and research is being directed toward the development of combinations of resins and reinforcements that have a high degree of heat resistance. Standard design data are needed for heat-resistant plastic materials to show the effects of elevated temperatures, for various periods of exposure, on their strength and related properties. To provide such design data for currently available plastics over their useful temperature range, the Forest Products Laboratory is engaged in a program of research and evaluation, in cooperation with the Air Force Materials Laboratory and materials manufacturers.

The scope of the program includes the evaluation of the effect of the following:

- (A) Time and temperature on the deterioration of plastics, as measured by weight loss.
- (B) Duration of exposure in an unstressed state at elevated temperatures on the mechanical properties in flexure, tension, compression, bearing, and shear (both interlaminar and edgewise).
- (C) Duration of exposure at constant tensile and compressive loads at elevated temperatures on strength and deformation.

Previous reports in this series are listed at the end of this report.

This particular report presents design criteria at elevated temperatures for an epoxy laminate, ERSB-0111 resin and 181-S-HTS glass fabric. The material used in this investigation was like that reported on in RTD-TDR-64-4154 (9)¹ except that the reinforcement was "S" glass fibers instead of "E" glass.

The current temperature range referred to here is from room temperature (about 80° F.) to 1,000° F. (27° to 538° C.), and the duration of exposure (soak period) is from a few minutes to 1,000 hours.

¹Underlined numbers in parentheses refer to specific reports listed in the Bibliography at the end of this report.

II. MATERIAL

Laminated panels of epoxy resin reinforced with glass fabric were furnished by the Union Carbide Plastics Company, Bound Brook, N.J. Information supplied with material is as follows:

Resin--ERSB-0111

Catalyst--1-1/2 percent BF_3 monoethylamine on resin solids

Fabric--S994 glass, 181 weave and HTS finish

Number of plies--12

Fabric orientation--Not nested but parallel laminated

Resin content--37 percent, impregnated from solution

Precure--None

Cauls--Polished steel with silicone release agent

Cure--1 hour at 160° C. (320° F.) and 200 pounds per square inch, then 2 hours at 190° C. (374° F.). Cool and discharge from press.

Postcure--6 hours at 205° C. (401° F.)

Union Carbide Plastics Company furnished 26 panels, 1/8 inch thick and 22 inches square. The Forest Products Laboratory determined the average specific gravity to be 1.80, the average Barcol hardness to be 75, and the average resin content from burnoff tests to be 35 percent.

It should be noted that this material was fabricated like the "E" glass laminates investigated in report RTD-TDR-63-4154 (9) except that here the "S" glass was laminated with a pressure of 200 pounds per square inch instead of 100 pounds per square inch.

III. TEST METHODS

Each mechanical test was made in accordance with generally accepted engineering practices, summarized as follows:

<u>Mechanical Test</u>	<u>Federal Test Method Standard No. 406</u>	<u>ASTM Method</u>
Flexure	1031	D 790-49 T
Tension	1011	D 638-60 T
Compression	1021	D 695-63 T
Interlaminar sheer	1042 (clamped)	None ²
Bearing	1051	D 953-54 (Method A)
Tensile stress-rupture	1063	None
Compressive stress-rupture	None	None
Weight loss	7041	None

The test methods used in this study are described in these references, and the apparatus used is described in the appendix of ASD Technical Report 61-482 (5).

IV. PRESENTATION OF DATA

Table 1 presents the results of preliminary quality tests of these laminates. The specimens were cut and tested so that the fiber stress was applied parallel to the warp direction of the fabric. Flexure specimens were 1/8 inch thick by 1 inch wide by 4 inches long, and compression specimens were 1/8 inch thick by 3/4 inch wide by 3-1/8 inches long with a 1/2-inch-wide net section. Compression specimens were laterally supported and loaded at a rate of head motion of 0.007 inch per minute, so that load-deformation data could be obtained. Each value shown for flexure and compression is the average of five specimens.

Tables 2 through 9 present the results of tests to determine the effects of different elevated temperatures for various periods of exposure on properties of this material. Strength properties shown for each specific temperature are based on tests of specimens that were both soaked and tested at that

²—However, Method VI of the Aircraft Research Technical Committee No. 11 was used.

temperature. All data, except in Tables 4 and 7, indicate properties after exposure of specimens in the unstressed state. Tables 4 and 7 present stress-rupture and creep data that were obtained from specimens exposed in the stressed state. After some of the unstressed soak periods, strength properties could not be measured or were zero. Unless otherwise noted, each value in the tables, except in Tables 4 and 7, is the average of five specimens. Values in Tables 4 and 7 are from individual specimens unless otherwise noted.

Figures 1 through 18 show the effects of soak periods at elevated temperatures on the various properties. Data were plotted from the tables. Smooth curves have been drawn to approximate the plotted points. The symbol \leq is used in conjunction with the plotted points at zero strength. Data so indicated are from specimens that had become so weakened that they fell apart during handling at the indicated exposure period. Obviously, the strength or stiffness was nil at some soak period less than that indicated but the exact time of zero strength is unknown.

The relative amount of creep at various stress levels for three temperatures is shown in Figures 8 and 14, based on data in Tables 4 and 7. At each stress level, a short horizontal line shows the creep that occurred from the time of initial loading until the specimen failed or was removed from the creep machine. The creep line at individual stress levels is shown beginning at an "average" stress-strain curve obtained from strength tests loaded to failure in about 3 minutes, and ending when the specimen failed or the test terminated at 1,000 hours.

Figures 17 and 18 present curves that summarize the effect of temperature on five mechanical properties after exposure for 0.5 and 100 hours. All strengths are shown as percentages of their respective room-temperature values. The curves are based on values from other strength-time plots in this report.

V. DISCUSSION OF RESULTS

Preliminary quality tests (Table 1) of this epoxy resin laminate reinforced with 181-S-HTS glass fabric showed results that were generally in agreement with MIL-R-9300A requirements. On the basis of this sampling, the following comprehensive evaluation was made:

Weight Loss

Deterioration due to continued exposure to elevated temperatures was measured through the loss of weight by the flexure specimens during their respective exposure periods (Table 2). Weights retained are shown as percent of initial weight in Figure 1 for various temperatures and periods of exposure at these elevated temperatures. The data show that at 300° and 400°F. for exposures of from 0.17 hour to 1,000 hours, the specimens lost less than 2 percent of their weight. Increases in temperature above 400° F., which was the postcure temperature, reduced weight retention at all periods of exposure; of course there was further reduction in weight retention with increases in duration of exposure. Rapid weight losses were experienced above 400° F. It appears rapid losses occurred at temperature and exposure conditions that cause losses greater than 10 percent.

Flexure

The results of flexure tests, as presented in Table 2 and Figures 2, 3, and 4, show the effect of time and temperature on the modulus of rupture and the modulus of elasticity, and the effect of weight loss on strength at various temperatures and periods of exposure. At constant temperatures of 300° and 400° F., the strength-exposure curves (Fig. 2) show large strength losses with the first application of heat (0.17 hour duration), and then show a slight increase in strength with increases in duration of exposure. After 1,000 hours the 300° F. curve reached 72 percent of room temperature value, and the 400° F. curve reached 42 percent. At constant temperature of 500° F., the strength dropped rapidly in the first 0.17 hour, dropped slowly for 24 hours, raised to a peak of 46 percent at 200 hours, and then dropped to almost zero at 1,000 hours. At temperatures of 600° F. and above, all strengths are less than 10 percent of room temperature value. The flexural modulus of elasticity at various exposures (Fig. 3) has about the same pattern as that for modulus of rupture.

Since weight loss determinations in this series of tests were made on flexure specimens, the data could provide a direct comparison of flexural strength with weight loss. Such a comparison was attempted in Figure 4. The envelope of values, which usually converges to zero at some resin content, is certainly not well defined because of the wide range in values.

Tension

The results of tension tests, presented in Tables 3, 4, and 5 and Figures 5 through 10, show the effects of exposure on several properties.

The results of tension tests at 0° to warp (Tables 3 and 4 and Figs. 5, 6, 7, and 8) show the detrimental effects of time and temperature on strength and elongation in a direction of loading where the glass fibers play a major role. Figure 5 shows the relative strength values for temperatures through 1,000° F. The 300° F. strength-exposure curve is relatively constant at about 85 percent of room temperature strength. The 400° F. strength-exposure curve is constant at 85 percent for 6 hours, which was the postcure time and temperature, and then decreases to about 40 percent for longer exposures. Strength-exposure curves for temperatures of 400° F. and above are long wavy lines.

The 500° F. curves were so unusual that exposure evaluations were repeated to verify the weakness at 6, 48, and 196 hours. Strengths at these exposures are only 23 to 35 percent of room temperature values. There is a tendency to form a plateau below 40 percent of room temperature value. The pattern of these curves is entirely different than that for "E" glass shown on Figure 5 of RTD-TDR-63-4154. For "E" glass, the stress-rupture curves formed a plateau at a strength greater than 80 percent of room temperature value. In general the "E" glass laminate was stronger and displayed more consistent decreases in strength with exposure.

Figure 6 shows irregular stiffness characteristics. The modulus of elasticity curves have peaks at various exposure periods.

The results of tension tests at 45° to warp (Figs. 9 and 10) show the detrimental effects of time and temperature on strength in a direction of loading where shear stresses between fibers in the resin provide resistance to the tensile force. In this direction of loading, the detrimental effect of time and temperature is greater than that at 0° tensile loading (Fig. 5), and about equal to that in flexure (Fig. 2). It can be shown that the edgewise shear strength is related to the tensile properties at 0° and 45° to the warp (5). Hence the effects of exposure shown by the 0° and 45° data are applicable to the effect of exposure on edgewise shear properties.

The results of tension tests at constant loads (Table 4, Figs. 7 and 8) show the effect of stress, temperature, and time on strength and creep. The effects of temperature and time previously discussed were obtained on unstressed specimens that were loaded to failure after exposure, but the creep and stress-rupture tests provided data on specimens that were loaded at a constant stress during exposure. Creep specimens tested at elevated temperatures were heated at their respective temperatures for about 0.5 hour or until a steady-state condition was attained before constant load was applied.

A comparison of the strength data obtained as a result of exposure in the unstressed as well as in the stressed condition is shown for three temperatures in Figure 7. The stress-rupture data are represented by solid lines and the data for unstressed material, i.e. strength-exposure curves, by broken lines--the latter being transferred from Figure 5.

The stress-rupture values at room temperature and at 300° F. are lower, as expected, than their respective strength-exposure curves. However, the stress-rupture values at 500° F. are greater than the strength-exposure values between 1 hour and 1,000 hours of exposure. This phenomenon was, of course, questioned.

Additional specimens were tested between 10 and 150 hours' duration to check this peculiar trend. These specimens were cut from the same laminate as the strength-exposure specimens. After checking both strength-exposure behavior and stress-rupture behavior, as well as equipment, it was observed that the failed specimens had a different type of failure in the two tests at the same temperature. The stress-rupture specimens delaminate with ragged tearing as the specimen failed. The strength-exposure specimens failed cleanly or brashly. We might theorize that unstressed exposure causes the resin to shrink and hence buckle or even break some glass fibers, whereas the stressed-exposure keeps the fibers taut and the resin shrinks tighter around the fibers. Whatever action was involved, it resulted in the unstressed values being less than the stressed values.

Strain data were also observed during the stress-rupture tests. Strains observed at full load were about the same as those observed at the same stress when the material was loaded in the short-time tension test after 0.5-hour exposure to temperature. To eliminate unmeasured strains resulting from the heating and the original alinement of fixtures, only the creep data are presented in Table 4 and in Figure 8. In Figure 8, these creep values have been added to the average stress-strain curve for the material. The length of the creep lines in Figure 8 shows that at room temperature there is very little creep, but as the temperature increases to 500° F., the amount of creep increases considerably. As a matter of fact, the total strain at 500° F. at the various stress levels is greater than 0.020 inch per inch, and the total strain at 500° F. of unstressed exposure (Table 3) is generally appreciably less than this value. This indicates an increase in plasticity which undoubtedly affected the strength.

Compression

The results of the compression tests, which were obtained by loading parallel to the warp direction of the laminate, are presented in Tables 6 and 7 and Figures 11 to 14. These data show the effects of exposure on specimens in both the stressed and unstressed condition. Figures 11 and 12 show the compressive strength and modulus of elasticity of specimens after exposure to various temperatures for various soak periods in the unstressed condition. Rapid heating and soaking for only the duration of the load causes an initial drop in strength at all temperatures. After this initial soak period of only 0.05 hour, the strength-exposure curve at 300° F. increases with increases in time; all the other curves, except the 500° F. temperature, remain essentially constant with time until permanent degradation occurs. The 500° F. strength-exposure curve has that unusual rise, like the flexure curve, after 24 hours.

Figure 13 shows the effect of exposure on compressive strength in the stressed condition. The stress-rupture data in this figure are shown as solid lines and compared with the strength-exposure data, dashed lines, from Figure 11. These stress-rupture curves are lower for each temperature than its respective strength-exposure curve, and not like the tensile characteristics. The slope of the room temperature and 500° F. stress-rupture curves are about equal. At 300° F., the strength-exposure curve showed a strengthening with exposure, but at 300° F. the constant load caused degradation so that the net result is a stress-rupture curve with little slope. Also the unusual 500° F. strength characteristic of strength-exposure curve is not reflected in the 500° F. stress-rupture curve.

Strain data were also observed during the stress-rupture tests. Strains observed at full load were about the same as those observed at the same stress when the material was loaded in the short-time compression test after 0.5-hour soak. To eliminate unmeasured strains during heating and alignment of fixtures, only the creep is presented in Table 7 and Figure 14. These creep values have been added to the average stress-strain curve for the material (Fig. 14).

Interlaminar Shear

Interlaminar shear strength results (Table 8) show the effects of time and temperature in a plane where the reinforcing fibers play a minor role. In this test the resin strength predominates. Figure 15 shows a fairly uniform drop in strength at 0.5-hour exposure with increasing temperature. Subsequent increase in soaking period at constant temperature causes little effect at 300° and 400° F. but at 500° to 700° F. strong peaks were measured.

Maximum Bearing Stress

The tests for maximum bearing stress that this material will sustain after exposure show the effects on a mechanical property that is a combination of tensile, compressive, and shear strengths. The results (Table 9), however, do not indicate the effects to be cumulative. The magnitude and pattern of the strength-exposure curves (Fig. 16) is similar to that exhibited by the other mechanical tests.

VI. SUMMARY OF RESULTS

In general, the exposure of the glass-reinforced plastic laminates to elevated temperatures less than 1,000° F. eventually reduces the strength to zero. The data and curves indicate the strength available for use at various temperatures and soak periods.

The amount of available strength varies with the property evaluated, period of exposure, and temperature of exposure. Available strengths are summarized for five mechanical tests after 0.5 and 100 hours of exposure in Figures 17 and 18. The curves in Figure 17 show that tensile strength in excess of 70 percent of room temperature value is available through 500° F.; all other strengths are about 20 percent at 500° F., decreasing uniformly from room temperature. Figure 18 shows the strengths retained after 100 hours. The pattern of tensile strength has changed considerably, but others have not changed as much.

Because the laminates in this study were made with the same resin system as the laminates in the study reported in RTD-TDR-63-4154, except that S-HTS glass was used instead of "E" glass with A1100 finish, the effect of temperature at 0.5 and 100 hours should be compared. At 0.5 hour the strength curves of compression, flexure, shear, and tension at 45° are about the same for both reinforcements (Fig. 16 of RTD-TDR-63-4154 and Fig. 17 of this report). However, at 0.5 hour the tension at 0° curves show "S" reinforcement as being weaker and irregular. After 100 hours of exposure (Fig. 17 of RTD-TDR-63-4154 and Fig. 18 of this report) the two materials have about the same strength, except for tensile characteristics, up to 400° F. At the 400° F. the "S" glass laminates have a plateau whereas the "E" glass laminates did not. The tensile characteristics of the "S" glass laminates were weaker than those for "E" glass.

The test data and curves presented in this report show that strength generally drops with the first application of heat. The tensile strength was affected in a most unusual way as shown on the curves. Above 400° F., the material was unstable with increasing temperature and soak time until permanent deterioration occurred.

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TABLE 1.--RESULTS OF PRELIMINARY QUALITY TESTS OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-S-HTS GLASS FABRIC

Designation	Flexure	Compression
Modulus of elasticity	Fiber stress at proportional limit	Modulus of elasticity: proportional stress limit
Primary:Secondary	Primary:Secondary	Primary:Secondary
Million: P.s.i.	1,000 : P.s.i.	1,000 : P.s.i.
Average of five	3.59 : 2.92	76.3 : 86.7
Standard deviation:	.11 : .04	1.6 : .33
MIL-R-9300A	3.2 : .	70.0 : .
TESTED AT 500° F. AFTER 0.5 HOUR AT 500° F.		
Average of five	2.17 : 15.5	19.0 : 2.35
Standard deviation:	.05 : 1.5	1.4 : .25
MIL-R-9300A	2.0 : .	22.0 : .
TESTED AT 500° F. AFTER 192 HOURS AT 500° F.		
Average of five	2.50 : 19.9	41.4 : 2.76
Standard deviation:	.06 : 1.7	2.3 : .11
MIL-R-9300A	1.8 : .	18.0 : .

TABLE 2.--FLEXURAL PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 161-S-HTS GLASS FABRIC

Temperature:	Duration of exposure:	Modulus of elasticity:		Stress at proportional limit:		Modulus of rupture:			Weight loss:
		Value	Coefficient	Value	Coefficient	Stress	Coefficient	Percentage of room temperature stress	
<u>°F.</u>	<u>Hours</u>	<u>Million p.s.i.</u>	<u>Percent</u>	<u>1,000 p.s.i.</u>	<u>Percent</u>	<u>1,000 p.s.i.</u>	<u>Percent</u>	<u>Percent</u>	<u>Percent</u>
Room		3.87	2.9	19.5	15.5	85.3	2.9	100.0	
300	.17	3.21	2.3	22.2	7.4	50.0	4.1	58.6	0.02
	.5	3.25	3.5	23.7	7.9	55.8	4.4	65.4	.03
	1	3.18		22.4		55.4		64.9	.03
	2	3.25	1.8	22.5	5.0	57.2	2.8	67.0	.02
	6	3.31		24.0		57.2		67.0	.07
	16	3.39	2.0	21.6	3.9	59.0	2.9	69.2	.09
	24	3.30		24.2		54.0		63.3	.08
	48	3.42	6.3	23.8	7.4	60.0	2.5	70.3	.10
	96	3.38		21.5		60.1		70.4	.07
	192	3.37	3.3	20.7	8.4	60.6	2.7	71.0	.09
	384	3.45		24.8		60.8		71.3	.06
	576	3.35	2.2	24.9	13.3	61.9	4.6	72.6	.16
	768	3.44		22.8		63.0		73.8	.24
	1,008	3.39	2.3	19.8	10.7	60.2	2.7	70.6	.15
400	.17	2.79	2.7	21.8	12.6	32.4	3.8	38.0	.03
	.5	2.72	3.3	23.1	9.0	35.0	3.5	41.0	.07
	1	2.72	3.2	22.3	5.2	35.4	4.5	41.5	.04
	2	2.75		23.1		35.3		41.4	.09
	6	2.72	3.3	19.4	4.6	33.7	5.7	39.5	.17
	16	2.77		24.9		38.5		45.1	.11
	24	2.54	5.8	17.0	13.8	28.5	6.0	33.4	.50
	48	2.66		15.0		31.7		37.2	.58
	96	2.95	4.3	21.8	5.6	37.4	7.3	43.8	.23
	192	2.56		16.2		31.0		36.3	1.22
	384	2.66	2.8	11.8	9.4	33.1	11.1	38.8	1.60
	576	2.82		23.2		37.3		43.7	.89
	768	2.74		19.2		34.9		40.9	1.45
	1,008	2.79	3.2	17.6	6.8	37.4	2.5	43.8	1.83
500	.17	2.53	3.2	15.1	12.0	20.5	6.6	24.0	.10
	.5	2.39	3.3	10.9	8.0	17.4	5.6	20.4	.18
	1	2.39		11.4		18.7		21.9	.22
	2	2.37	5.9	7.8	9.6	15.7	4.3	18.4	.32
	6	2.05		7.4		14.1		16.5	.64
	16	1.81	2.1	7.4	3.5	12.8	4.8	15.0	1.36
	24	1.63		8.0		11.9		14.0	2.00
	48	2.04	4.0	7.0	15.6	15.4	3.8	18.0	3.22
	96	2.66		14.8		33.5		39.3	4.32
	192	2.80	2.2	13.7	10.8	39.0	5.5	45.7	5.29
	384	2.40		5.8		25.8		30.2	8.50
	576	2.01	6.7	3.8	9.6	14.0	3.5	16.4	12.0
	768	1.43		2.5		5.5		6.4	16.8
	1,008					1.9	16.1	2.2	21.4

TABLE 2.--FLEXURAL PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-S-NTS
GLASS FABRIC--continued

Temperature:	Duration of:	Modulus of	Stress at	Modulus of rupture	Weight				
	exposure	elasticity	proportional		loss				
			limit	Stress:Coeffi-	Percentage of:				
		Value :Coeffi-	Value :Coeffi-	cient ¹	room tempera-				
		cient ¹	cient ¹		ture stress				
			cient ¹						
<u>°F.</u>	<u>Hours</u>	<u>Million:</u>	<u>Percent:</u>	<u>1,000</u>	<u>Percent:</u>				
		<u>p.s.i.</u>	<u>p.s.i.</u>	<u>p.s.i.</u>	<u>Percent</u>				
600	0.17	1.08	14.3	4.9	11.8	7.7	5.6	9.0	1.07
	.5	.39	11.0	3.7	10.5	7.2	5.7	8.4	1.83
	1	1.30	10.3	3.8	6.9	7.7	4.4	9.0	1.22
	2	1.22	.....	3.6	.....	6.3	.....	7.4	1.76
	6	1.29	10.9	3.2	4.1	6.7	6.3	7.8	3.30
	16	1.13	.....	3.1	.....	6.8	.....	8.0	5.29
	24	1.24	6.2	3.2	15.3	6.9	7.6	8.1	5.64
	48	1.27	.....	3.5	.....	8.4	.....	9.8	7.42
	96	1.54	17.0	3.4	24.8	9.5	12.6	11.1	12.2
	192	.....	.....	.....	.....	.....	.....	.....	25.5
	384	.....	.....	.....	.....	.....	.....	.....	32.9
	576	.....	.....	.....	.....	.....	.....	.....	35.8
700	.17	.46	36.3	1.6	9.6	2.8	7.8	3.3	7.17
	.5	.47	14.2	1.6	1.3	3.1	8.0	3.6	11.2
	1	.81	.....	2.0	.....	5.5	.....	6.4	11.6
	2	1.37	8.9	5.2	25.4	11.0	2.2	12.9	13.6
	6	1.41	.....	4.1	.....	10.6	.....	12.4	15.9
	16	.....	.....	.....	.....	.....	.....	.....	32.5
	24	.....	.....	.....	.....	.....	.....	.....	33.8
800	.17	1.18	20.8	3.8	11.7	7.5	10.4	8.8	18.1
	.5	.....	.....	.....	.....	5.8	19.4	6.8	16.9
	1	.....	.....	.....	.....	.....	.....	.....	32.3
	2	.....	.....	.....	.....	.....	.....	.....	34.6
900	.17	.....	.....	.....	.....	5.1	11.2	6.0	20.2
	.5	.....	.....	.....	.....	.....	.....	.....	35.1
	1	.....	.....	.....	.....	.....	.....	.....	35.4
1,000	.17	.....	.....	.....	.....	.....	.....	.....	34.6
	.5	.....	.....	.....	.....	.....	.....	.....	35.6

¹Numerical values of coefficient of variation are computed for exposures with 5 replications; other exposures had only 2 replications.

(Sheet 2 of 2)

TABLE 3.--TENSILE PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-S-HTS GLASS FABRIC. TESTS MADE PARALLEL TO WARP DIRECTION

Temperature:	Duration of exposure	Modulus of elasticity	Stress at proportional limit	Maximum stress	Strain at maximum stress
		Value	Coefficient of variation	Value	Coefficient of variation
	</				

TABLE 4.--STRESS-RUPTURE AND CREEP DATA FROM TENSION TESTS OF ERSB-0111 RESIN
AND 181-S-HTS GLASS FABRIC

Applied stress:	Percentage of room temperature stress	Rupture time	Creep data at....					
			0.1 hour	1 hour	10 hours	100 hours	1,000 hours	Rupture
1,000 p.s.i.	Percent	Hours	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100	Inch per inch x 100
ROOM TEMPERATURE								
86.3	100							
80.0	92.7	0.010						0.071
75.0	87.2	.12	0.070					.314
70.0	81.1	1.25	.026	0.067				.070
65.0	75.3	7.8	.054	.080				.108
62.0	71.8	72	.071	.060	0.096			.102
61.0	70.7	240.4	.09	.034	.051	0.082		.088
60.0	69.5	58.45	.035	.054	.090			.176
59.0	68.4	54.15	.057	.071	.114			.123
55.0	63.7	844.4	.026	.040	.029	.040		.123
53.0	61.4	52	.118	.226	.360			.68
50.0	57.9	>1,000	.020	.040	.066	.068	0.185	
300° F.								
70.0	81.2	.001						
65.0	75.4	.008						
61.0	70.7	4.15	.060	.100				.102
60.0	69.5	.18	.228					.232
59.5	69.0	1.9	.022	.048				.054
59.0	68.4	24.9	.080	.109	.179			.208
58.0	67.2	8.1						.047
55.0	63.7	19.2	.034	.044	.097			.114
53.0	61.4	143.6	.017	.027	.067	.218		.282
52.0	60.3	506.7	.026	.026	.051	.131		.189
50.0	58.0	962.2	.020	.040	.094	.185		.420
500° F.								
60.0	69.6	.05						.699
59.0	68.4	.14	.484					.588
57.0	66.1	.75	.104					.134
55.0	63.7	3.25	.325	.482				.644
55.0	63.7	215.0						
50.0	57.9	23.0						
50.0	57.9	45.0	.108	.201	.392			.782
50.0	57.9	232.0						
45.0	52.1	183.7	.059	.130	.234	.590		.757
44.0	51.0	146.0						
40.0	46.4	308.7	.072	.156	.237	.652		1.54
36.0	40.6	337.6	.030	.087	.165	.433		.612
32.0	37.1	657.0	.060	.096	.227	.392		.874
30.0	34.8	>1,000	.014	.029	.038	.046	.186	

¹All specimens 1 inch wide by 30 inches long except as noted.

²Specimen 3/4 by 9-3/8 inches.

TABLE 5.--TENSILE PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-S-HTS GLASS FABRIC. TESTS MADE AT 45° TO THE WARP DIRECTION

Temperature	Duration of exposure	Modulus of elasticity	Stress at proportional limit	Maximum stress				
		Value	Coefficient of variation	Value	Coefficient of variation	Value	Coefficient of variation	Percentage of room temperature value
°F.	Hours	Million p.s.i.	Percent	1,000 p.s.i.	Percent	1,000 p.s.i.	Percent	Percent
Room	.....	2.05	5.5	3.6	14.0	26.7	11.2	100.2
300	.5	.74	4.7	2.8	7.0	15.9	6.1	59.7
	6	.90	7.4	3.2	9.1	17.7	7.2	66.2
	96	1.08	6.8	3.3	23.5	17.8	1.4	66.6
	1,000	1.23	15.0	3.6	9.4	19.4	10.0	72.6
400	.5	.47	3.3	2.1	7.1	10.5	10.3	39.3
	6	.64	.....	2.7	.....	12.2	.....	45.6
	96	.60	7.0	2.4	2.2	10.6	11.0	39.7
	1,000	.90	9.1	2.6	20.8	9.6	11.6	36.0
500	.5	.31	7.2	1.7	7.8	5.9	6.8	22.1
	6	.24	10.9	.7	28.0	4.1	7.5	15.4
	48	.56	11.4	1.0	11.0	6.5	9.6	24.3
	48	.34	.....	1.2	.....	4.7	.....	17.6
	192	.93	30.3	1.6	15.2	6.3	26.8	23.6
	192	1.02	.....	2.8	.....	9.4	.....	35.2
	576	0	.....	.....	.....	0	.....	0
600	.5	.19	12.4	1.1	7.0	3.7	11.8	13.8
	6	.17	8.7	.6	7.1	1.6	7.9	6.0
	48	.74	25.6	1.0	16.6	5.4	26.1	20.2
	96	0	.....	.....	.....	0	.....	0
700	.5	.05	18.7	.3	1.7	.6	7.5	2.2
	2	.40	13.5	1.0	11.5	5.3	10.5	19.8
	6	.....	.....	.....	.....	.4	14.2	1.5
800	.5	.64	11.0	1.3	18.6	4.0	9.0	15.0
	2	0	.....	.....	.....	0	.....	0
900	.5	.....	.....	.....	.....	0	.....	.....

TABLE 6.- COMPRESSIVE PROPERTIES OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-S-HTS GLASS FABRIC

[illegible]

TABLE 1.--STRESS-RUPTURE AND CREEP DATA FROM COMPRESSION TESTS OF EPOXY LAMINATES MADE OF
ERSB-0111 RESIN AND 181-S-ITS GLASS FABRIC

Applied stress		Percentage of room temperature stress	Rupture time	Creep data at....						
				0.1 hour	1 hour	10 hours	100 hours	1,000 hours	Rupture	
<u>1,000</u>	<u>Percent</u>	<u>Hours</u>	<u>Inch per</u>	<u>Inch per</u>	<u>Inch per</u>	<u>Inch per</u>	<u>Inch per</u>	<u>Inch per</u>	<u>Inch per</u>	<u>Inch per</u>
<u>p.s.i.</u>			<u>inch x 100</u>	<u>inch x 100</u>	<u>inch x 100</u>	<u>inch x 100</u>	<u>inch x 100</u>	<u>inch x 100</u>	<u>inch x 100</u>	<u>inch x 100</u>
AT ROOM TEMPERATURE										
147.9	100.0									
51.5	107.5	0.013								0.012
51.0	106.5	.13	0.023							.092
50.5	105.4	2.65	.012	0.020						.043
50.0	104.4	5.5	.040	.062						.071
47.0	98.1	15.5	.033	.049	0.072					.075
46.0	96.0	209.7	.012	.048	.079	0.115				.130
45.0	94.0	156.8	.033	.035	.058	.085				.085
44.0	91.9	7.6	.001	.004						.014
44.0	91.9	161.6	.035	.060	.075	.101				.104
42.5	88.7	283.2	.012	.030	.030	.053				.065
37.0	77.2	>1,000	.013	.030	.081	.103	0.164			
AT 300° F.										
129.5	61.7									
27.0	56.5	0.000								
25.0	52.3	.004								
23.0	48.2	.008								
22.0	46.0	.060								.034
21.0	44.0	.030								.080
20.0	41.9	.070								.031
20.0	41.9	285.0	.007	.012	.024	.039				.053
19.5	40.8	.5	.068							.080
19.3	40.4	124.0	.042	.067	.097	.127				.134
19.1	40.0	3.60	.037	.068						.076
19.0	39.8	.03								.024
19.0	39.8	114.0	.043	.072	.212	.322				.343
18.0	37.7	.07								.010
17.5	36.6	942.0	.064	.090	.110	.119				.220
17.0	35.6	>1,000	.006	.008	.009	.014	.016			
16.0	33.5	>1,000	.032	.046	.068	.074	.071			
AT 500° F.										
111.6	24.2									
11.0	23.0	.005								
10.0	20.9	.23	.094							.170
8.0	16.7	.37	.042							.102
7.0	14.6	1.9	.012	.028						.069
6.5	13.6	2.0	.016	.037						.077
6.2	13.0	6.9	.008	.029						.086
6.1	12.7	12.15	.023	.084	.260					.416
6.0	12.5	69.5	.038	.089	.242					.717
5.0	10.4	127.3	.022	.067	.243	.312				.336
4.0	8.4	505.9	.016	.028	.051	.180				.323
3.0	6.3	669.5	.017	.032	.048	.104				.324
3.0	6.3	148.1	.012	.077	.169	.525				.883

¹Average control strength at room temperature and at 300° F. and 500° F. after 0.5 hour at temperature.

TABLE 8.--INTERLAMINAR SHEAR STRENGTH OF EPOXY
LAMINATES MADE OF ERSB-0111 RESIN
AND 181-S-HTS GLASS FABRIC

Temperature:	Duration of:	Maximum shear stress		
	exposure	Value	Efficient	Percentage
				of room
				temperature
				value
<u>°F.</u>	<u>Hours</u>	<u>P.s.i.</u>	<u>Percent</u>	<u>Percent</u>
Room	:	3,240	10.5	100.0
300	: 0.5	2,340	10.3	72.2
	: 6	2,510	6.0	77.5
	: 96	2,600	5.0	80.2
	: 1,000	2,530	11.5	78.1
400	: .5	1,490	7.4	46.0
	: 6	1,590	16.4	49.1
	: 96	1,500	2.3	46.3
	: 1,000	1,390	9.4	42.9
500	: .5	670	6.4	20.7
	: 6	440	5.7	13.6
	: 48	1,500	3.9	46.3
	: 192	1,460	3.4	45.1
	: 576	0	.....	0
600	: .5	500	11.2	15.4
	: 6	250	12.0	7.7
	: 48	220	20.4	6.8
	: 96	50	38.0	1.5
700	: .5	180	10.0	5.6
	: 2	220	11.4	6.8
	: 6	660	16.7	20.4
	: 16	0	.....	0
800	: .5	250	6.0	7.7
	: 2	0	.....	0
900	: .5	60	21.7	1.8

TABLE 9.--MAXIMUM BEARING STRESS OF EPOXY LAMINATES MADE OF ERSB-0111 RESIN AND 181-S-HTS GLASS FABRIC

Temperature:		Duration of:	Maximum bearing stress		
		exposure	Value	Coeffi-	Percentage
				cient	of room
					temperature
					value
<u>°F.</u>	<u>Hours</u>	<u>1,000</u>	<u>Percent</u>	<u>Percent</u>	
		<u>p.s.i.</u>			
Room	.....	58.4	1.1	100.0	
300	0.5	33.9	6.3	58.0	
	6	41.1	2.2	70.4	
	96	41.3	9.2	70.7	
	1,000	46.1	7.8	78.9	
400	.5	24.8	17.3	42.5	
	6	30.0	5.4	51.4	
	96	26.2	10.9	44.9	
	1,000	29.0	11.8	49.6	
500	.5	12.7	9.4	21.7	
	6	12.1	13.3	20.7	
	48	20.5	6.2	35.1	
	192	27.8	3.3	47.6	
	576	0	.....	0	
600	.5	9.8	6.6	16.8	
	6	7.3	2.2	12.5	
	48	3.9	11.2	6.7	
	96	1.9	8.3	3.2	
700	.5	5.1	8.4	8.7	
	2	6.3	12.7	10.8	
	6	15.3	7.4	26.2	
	16	0	.....	0	
800	.5	13.3	4.0	22.8	
	2	2.9	30.1	5.0	
900	.5	4.2	20.0	7.2	

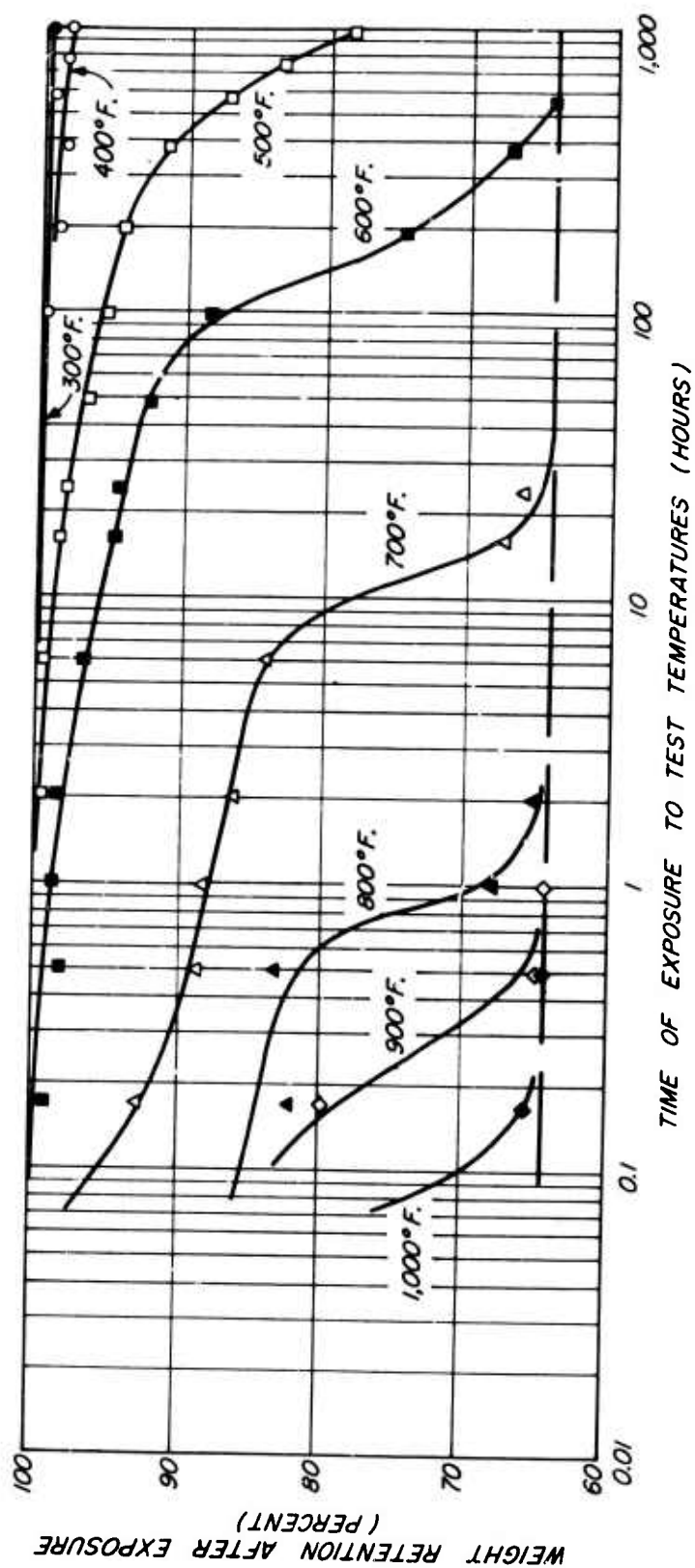


Figure 1.--Deterioration (as Weight Loss) at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

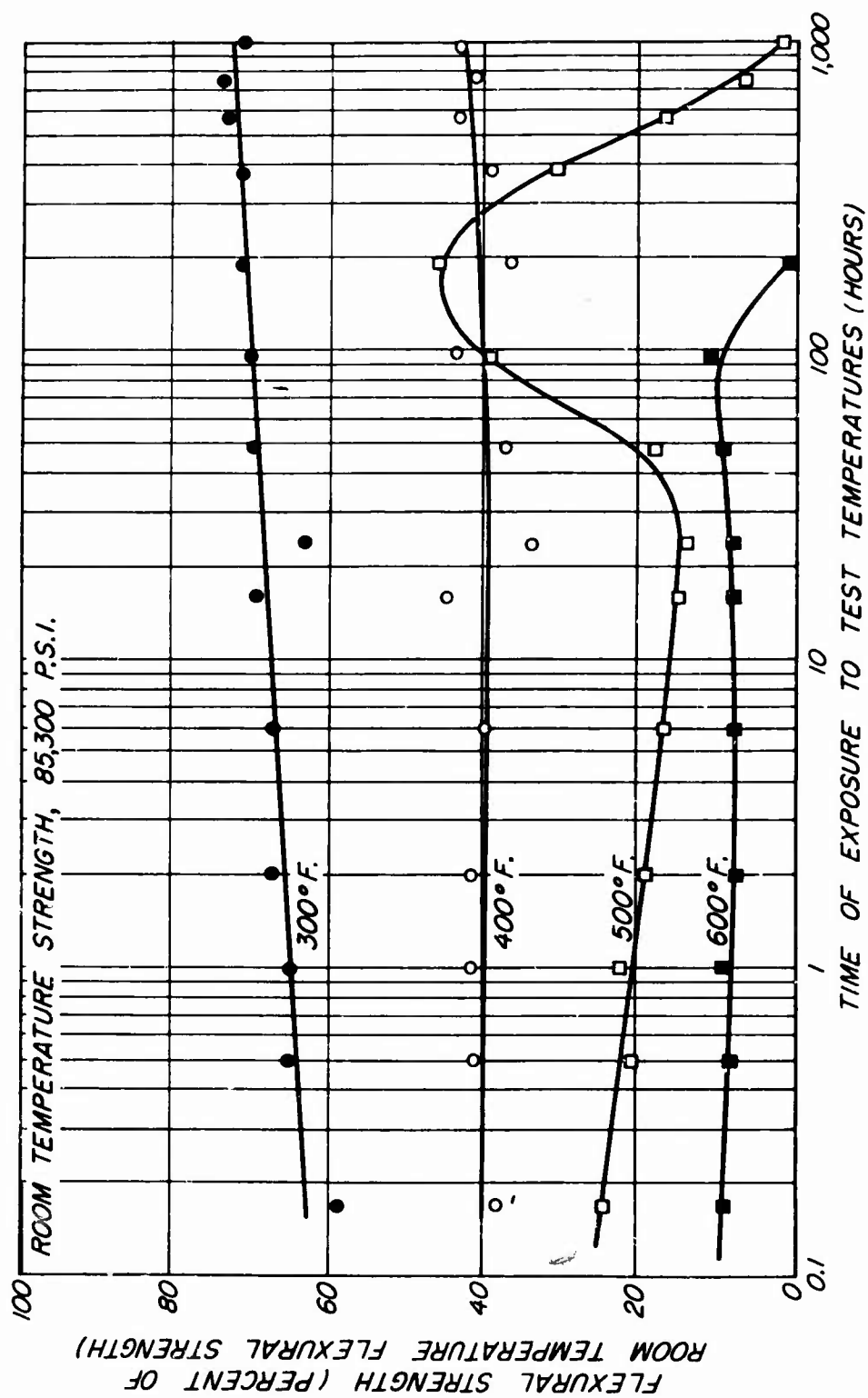


Figure 2. --Flexural Strength at Elevated Temperatures of Epoxy Laminates
Made of ERSB-0111 Resin and 181-S-HTS Class Fabric.

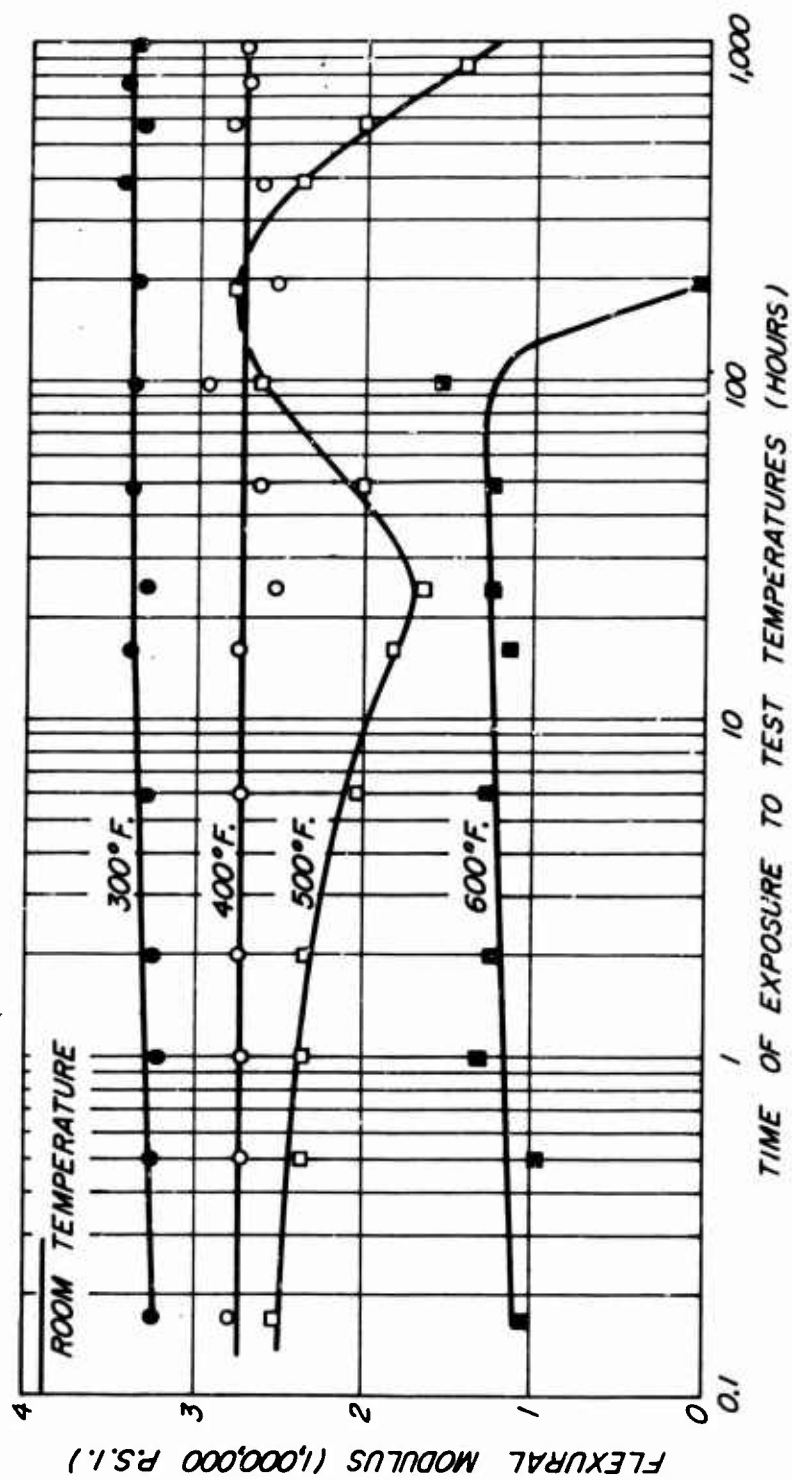


Figure 3. --Flexural Modulus at Elevated Temperatures of Epoxy Laminates
Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

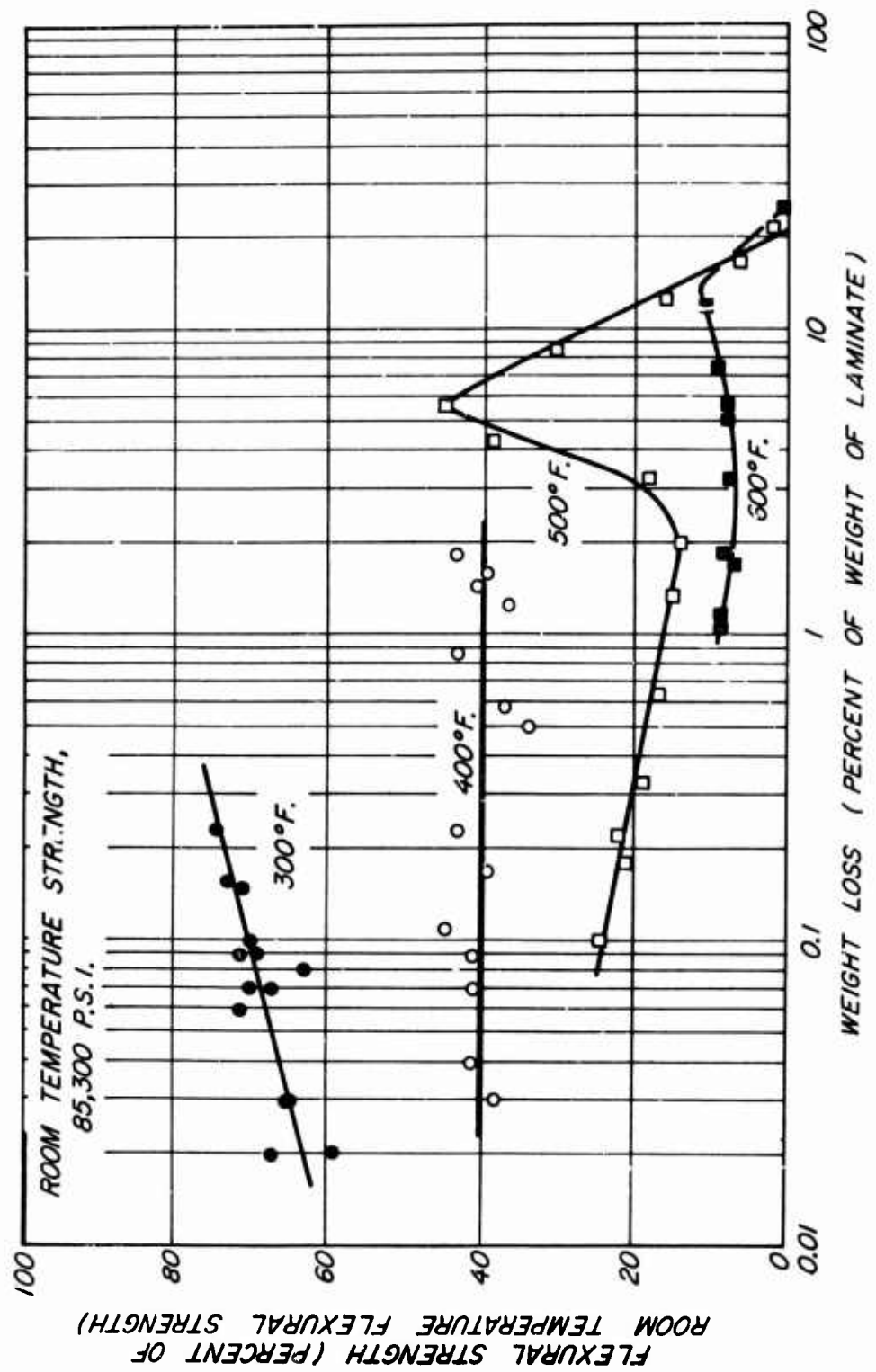


Figure 4. --Flexural Strength Versus Weight Loss at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

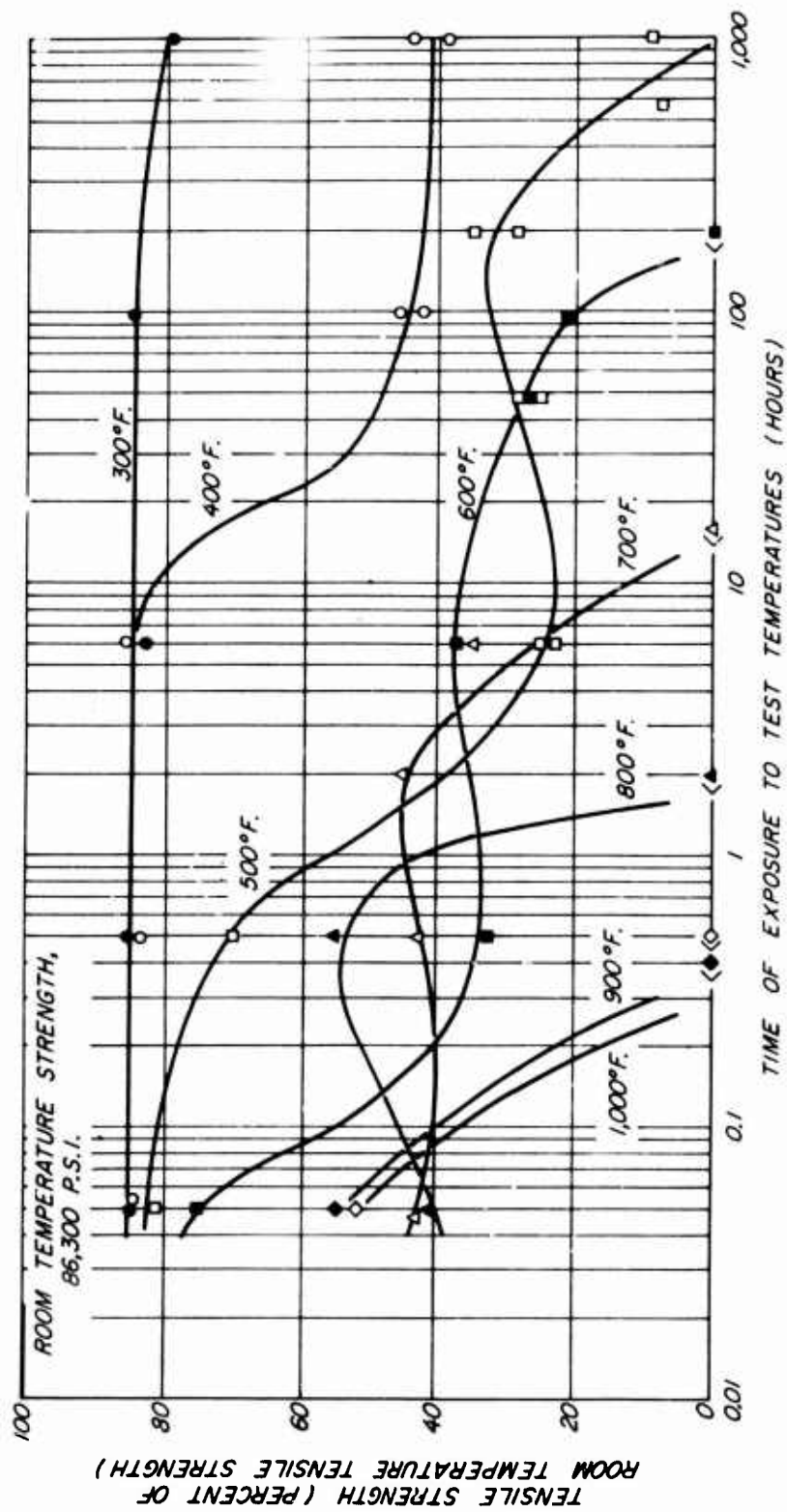


Figure 5.--Tensile Strength at Elevated Temperatures of Epoxy Laminates
Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric. Tests Made
Parallel to Warp Direction.

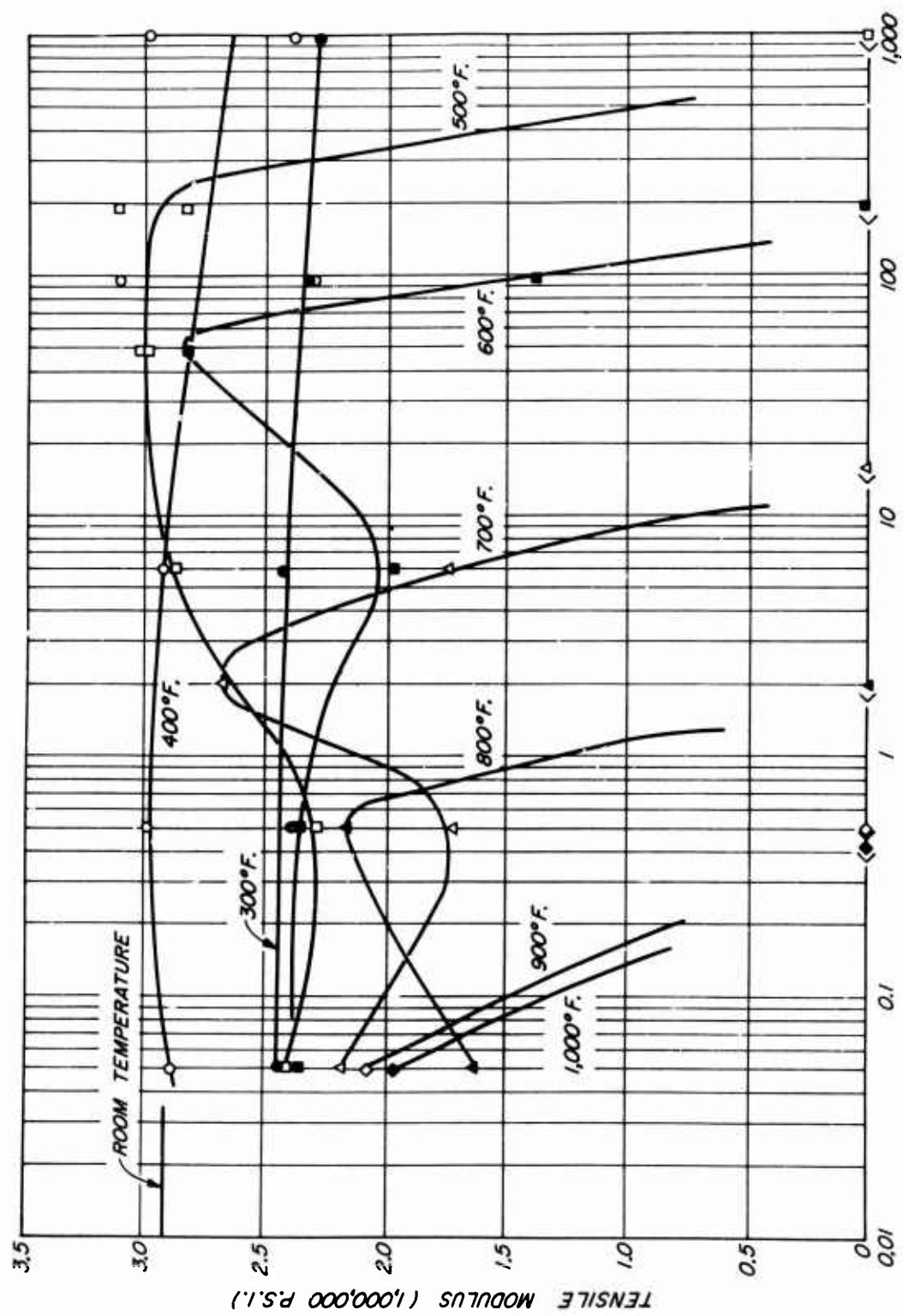


Figure 6. --Tensile Modulus at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric. Tests Made Parallel to Warp Direction.

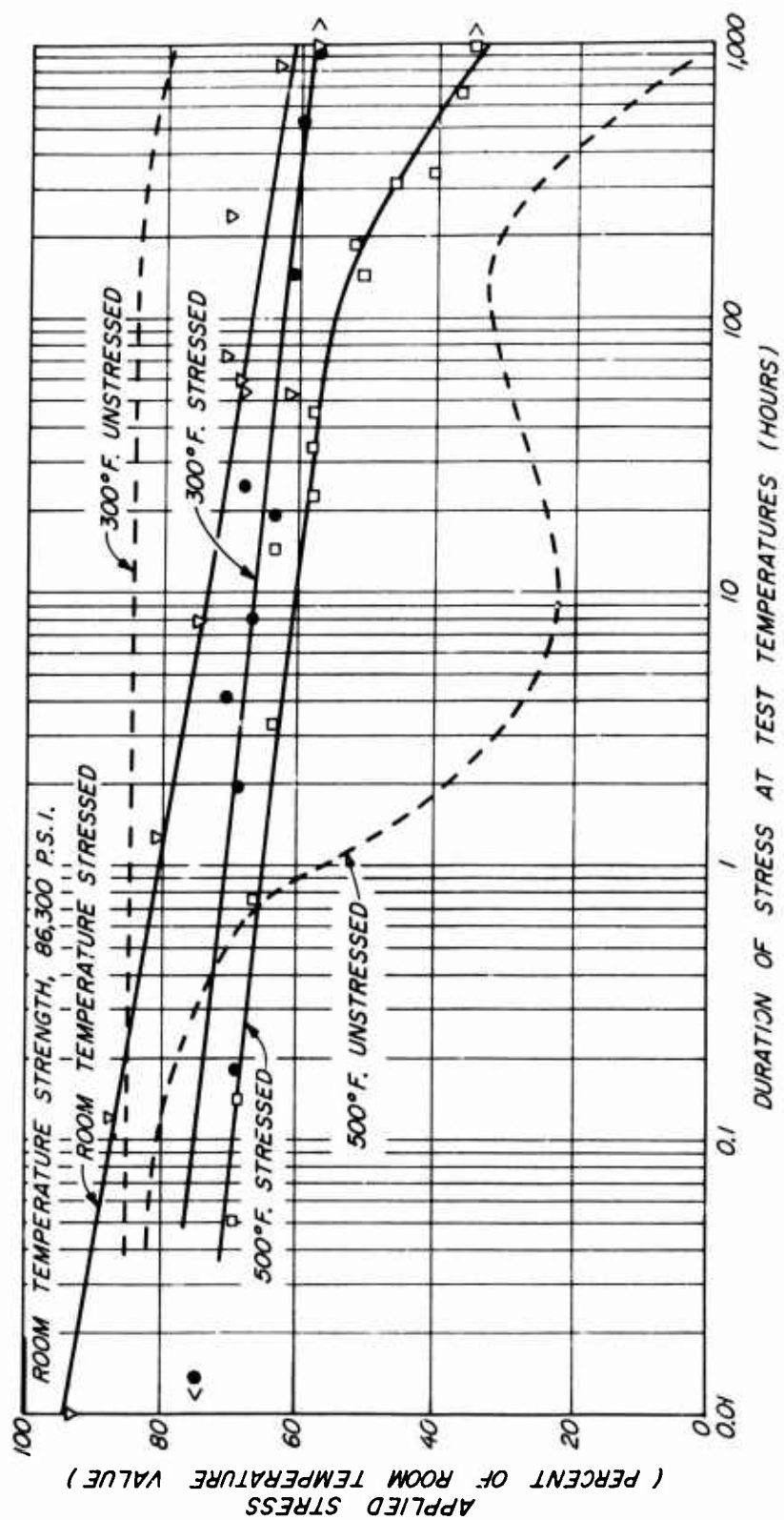


Figure 7. --Tensile Stress-Rupture Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric. Tests Made Parallel to Warp Direction.

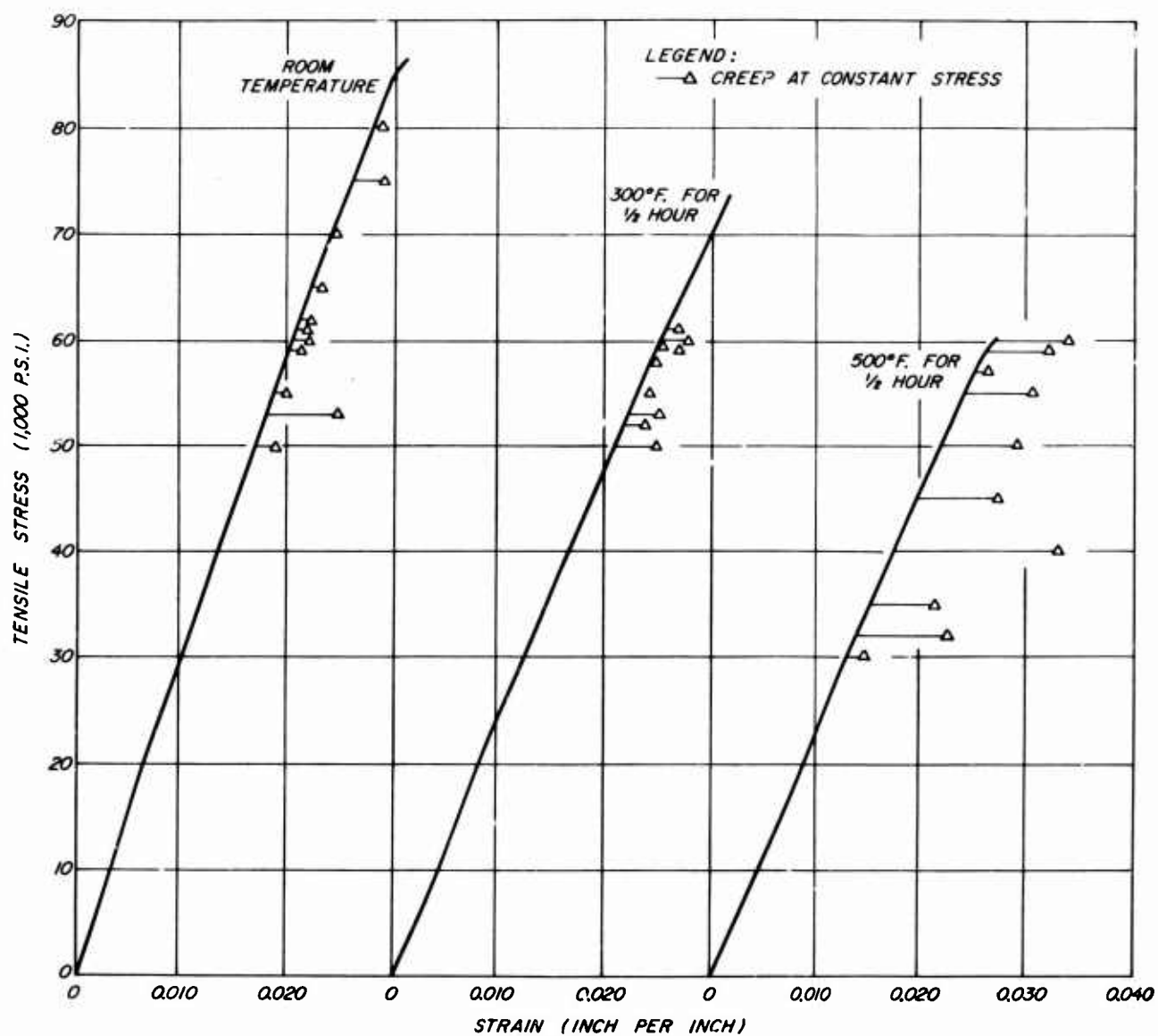


Figure 8. --Relationship of Tensile Creep at Various Stress Levels to Average Tensile Stress-Strain Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

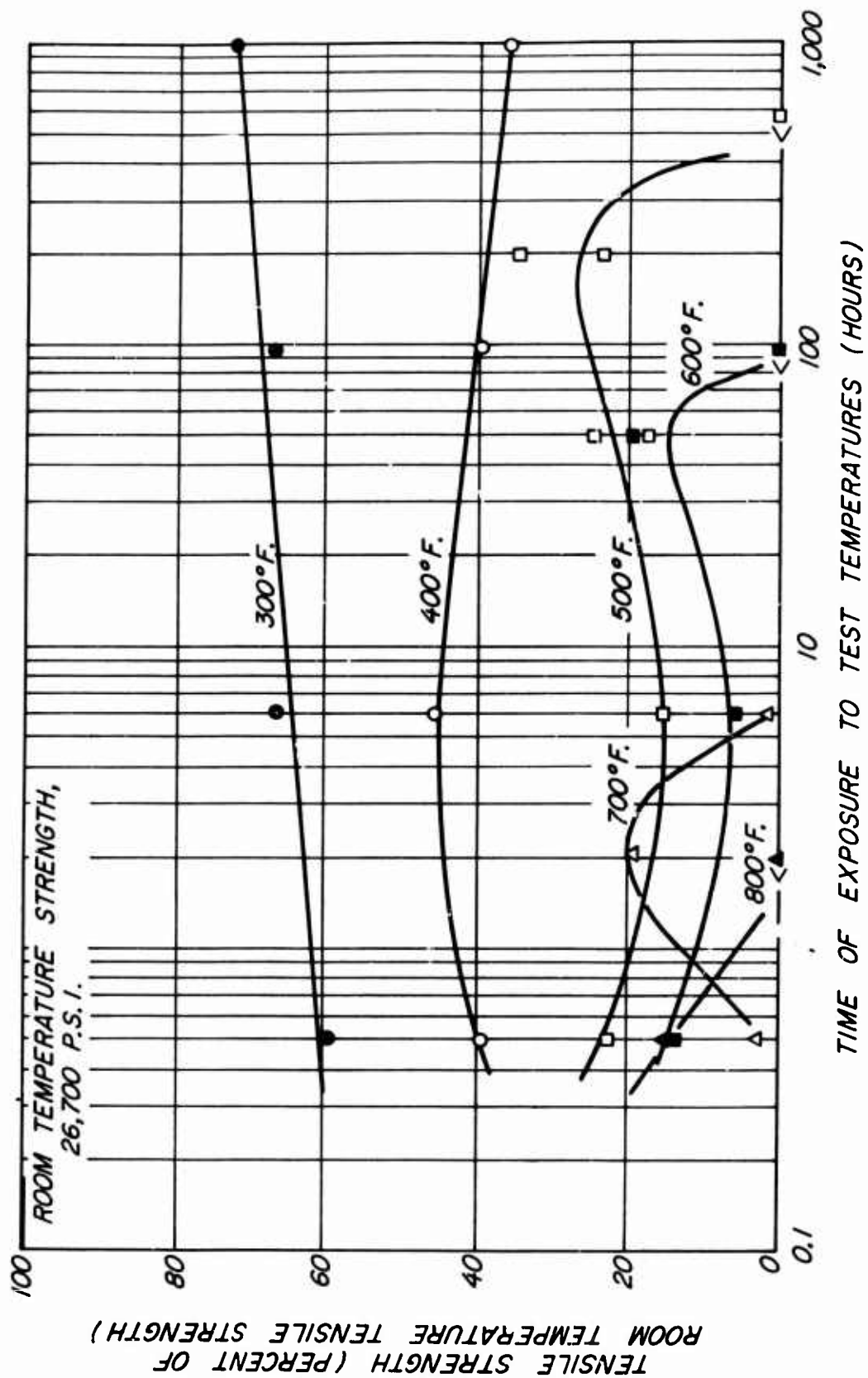


Figure 9. --Tensile Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric. Tests Made at 45° to the Warp Direction.

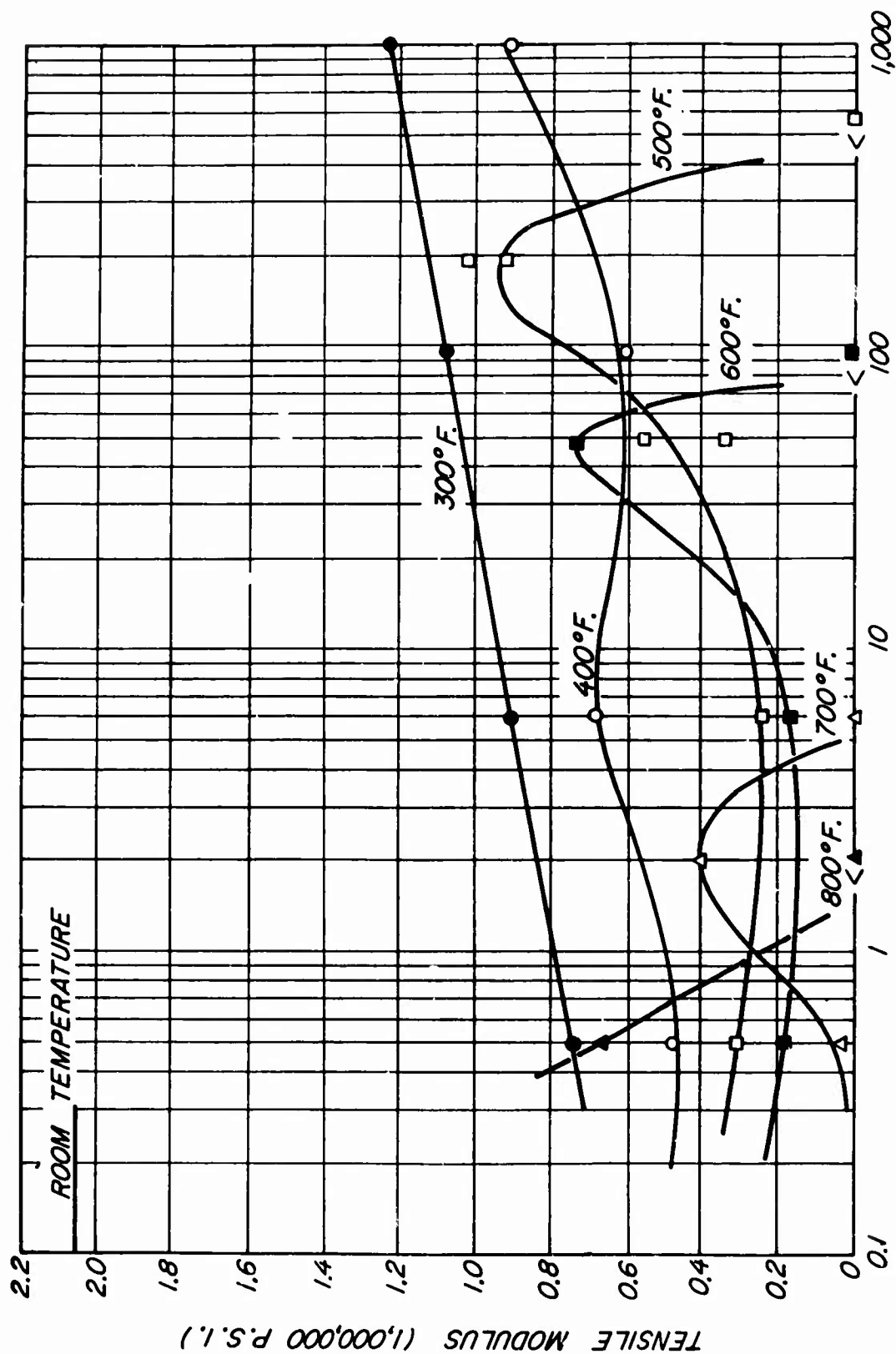


Figure 10. --Tensile Modulus at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric. Tests Made at 45° to the Warp Direction.

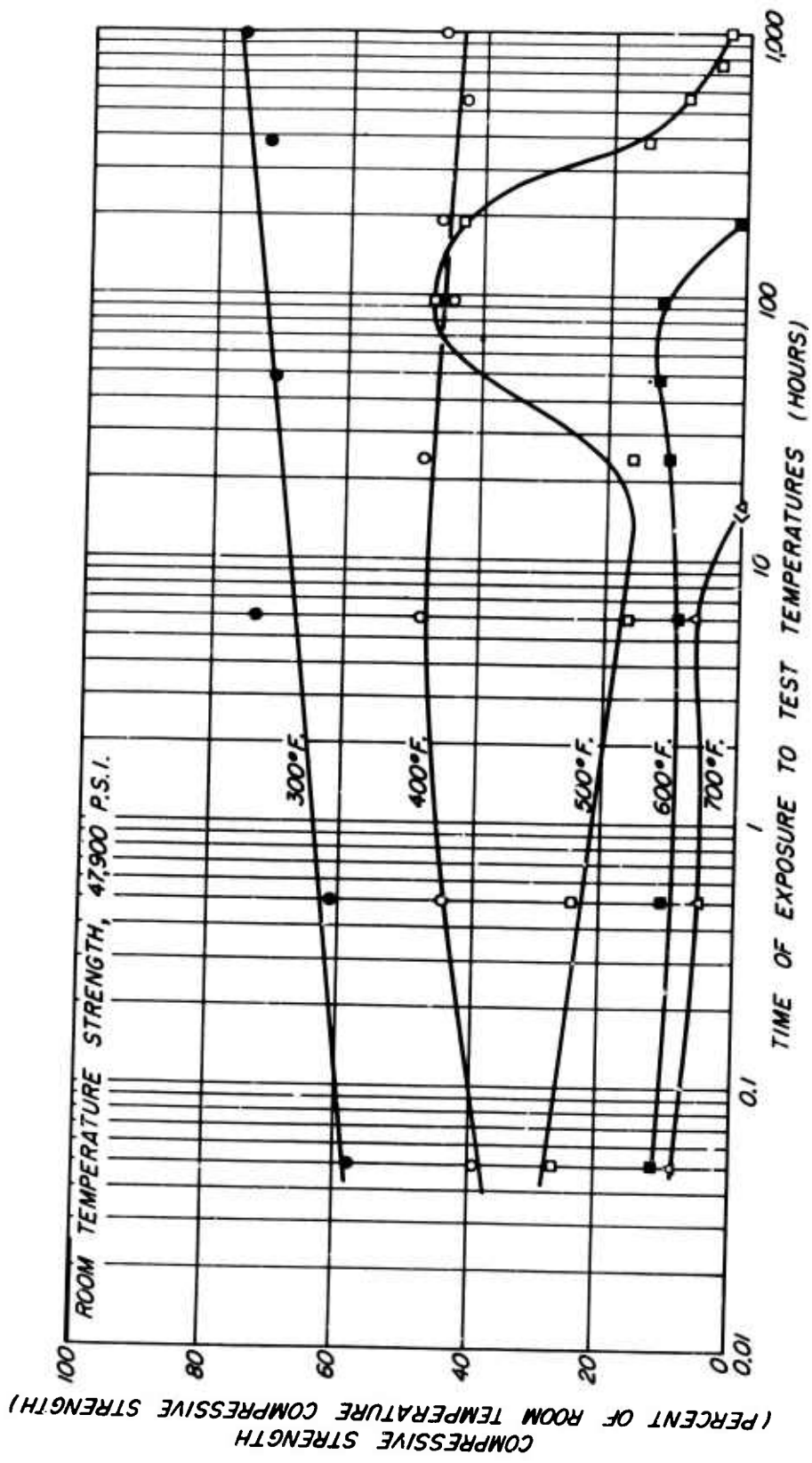


Figure 11.--Compressive Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

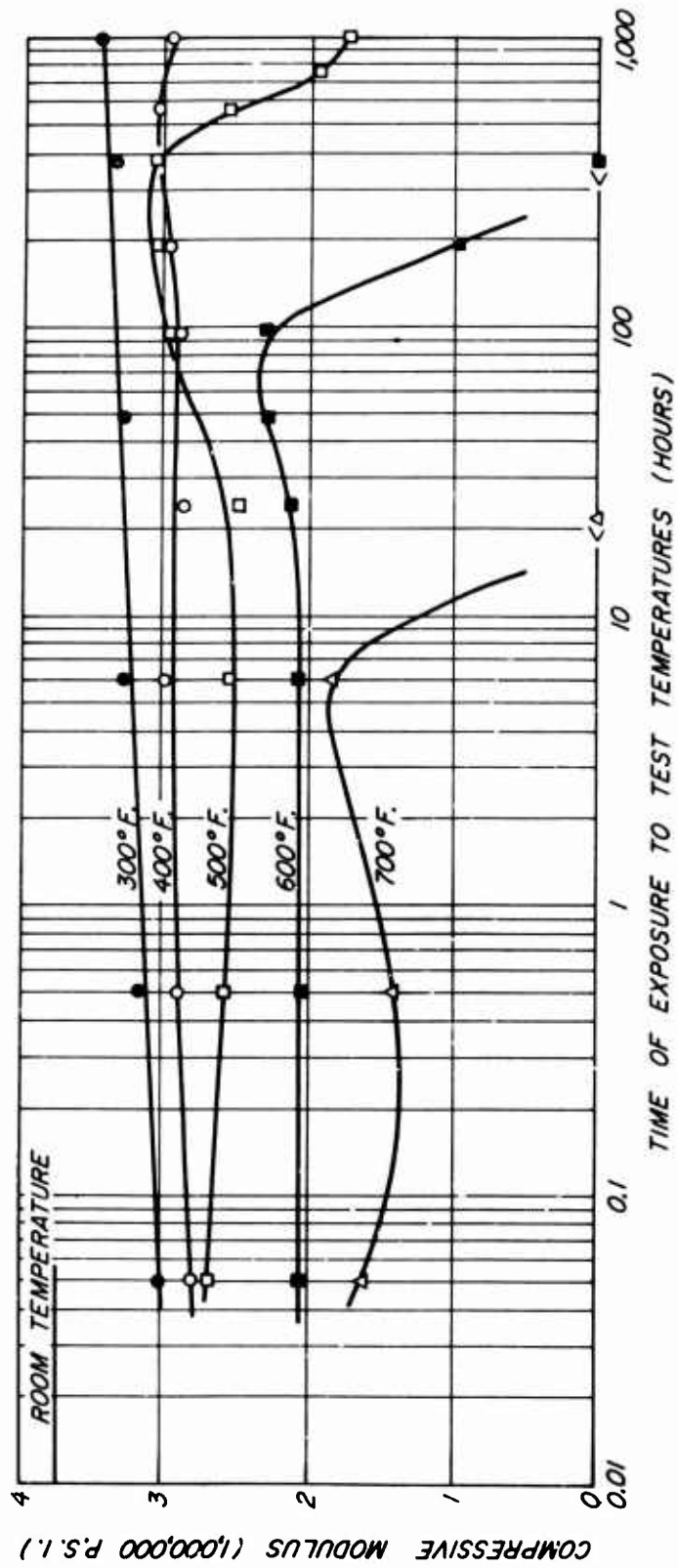


Figure 12. --Compressive Modulus of Elasticity at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

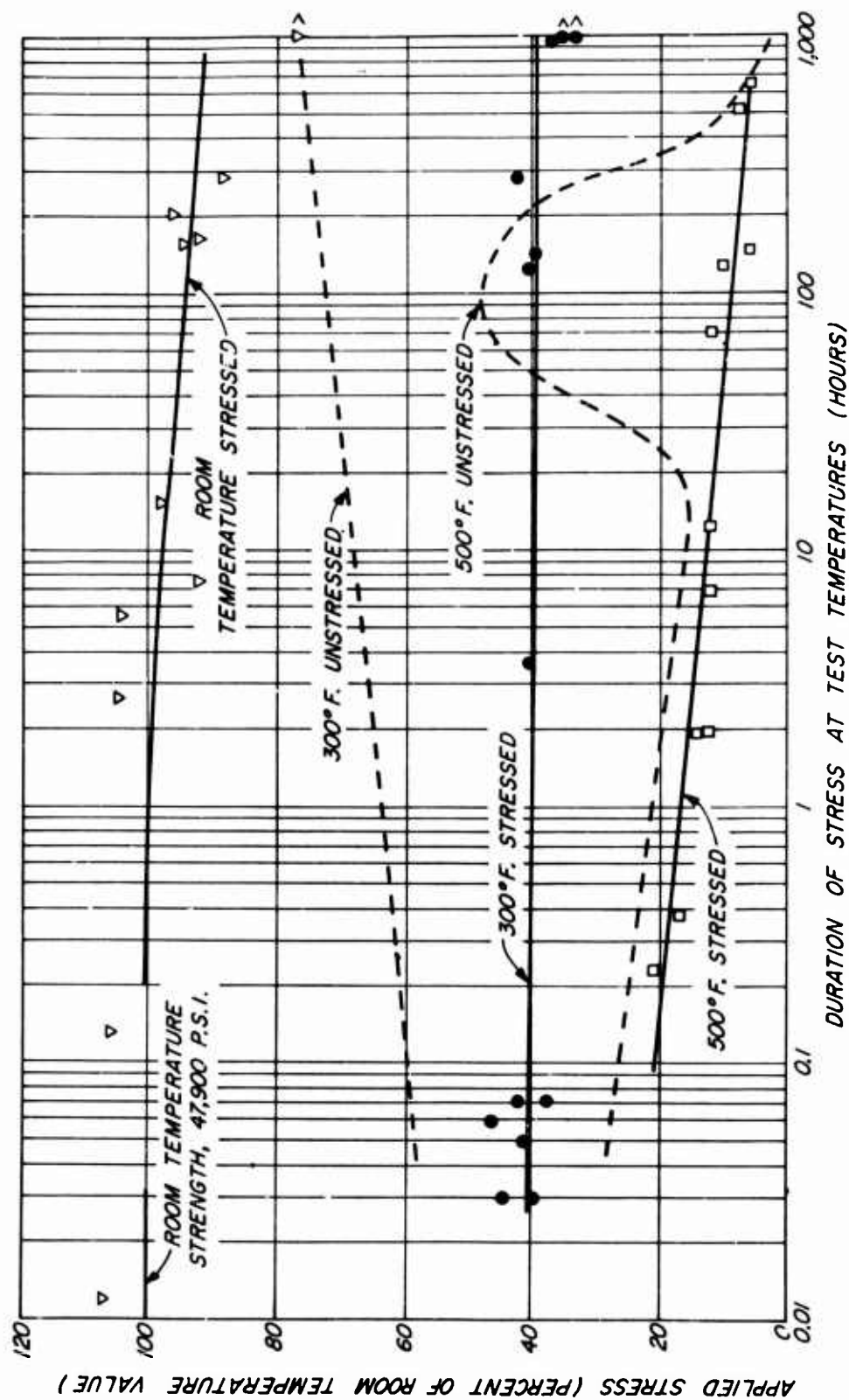


Figure 13. --Compressive Stress-Rupture Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

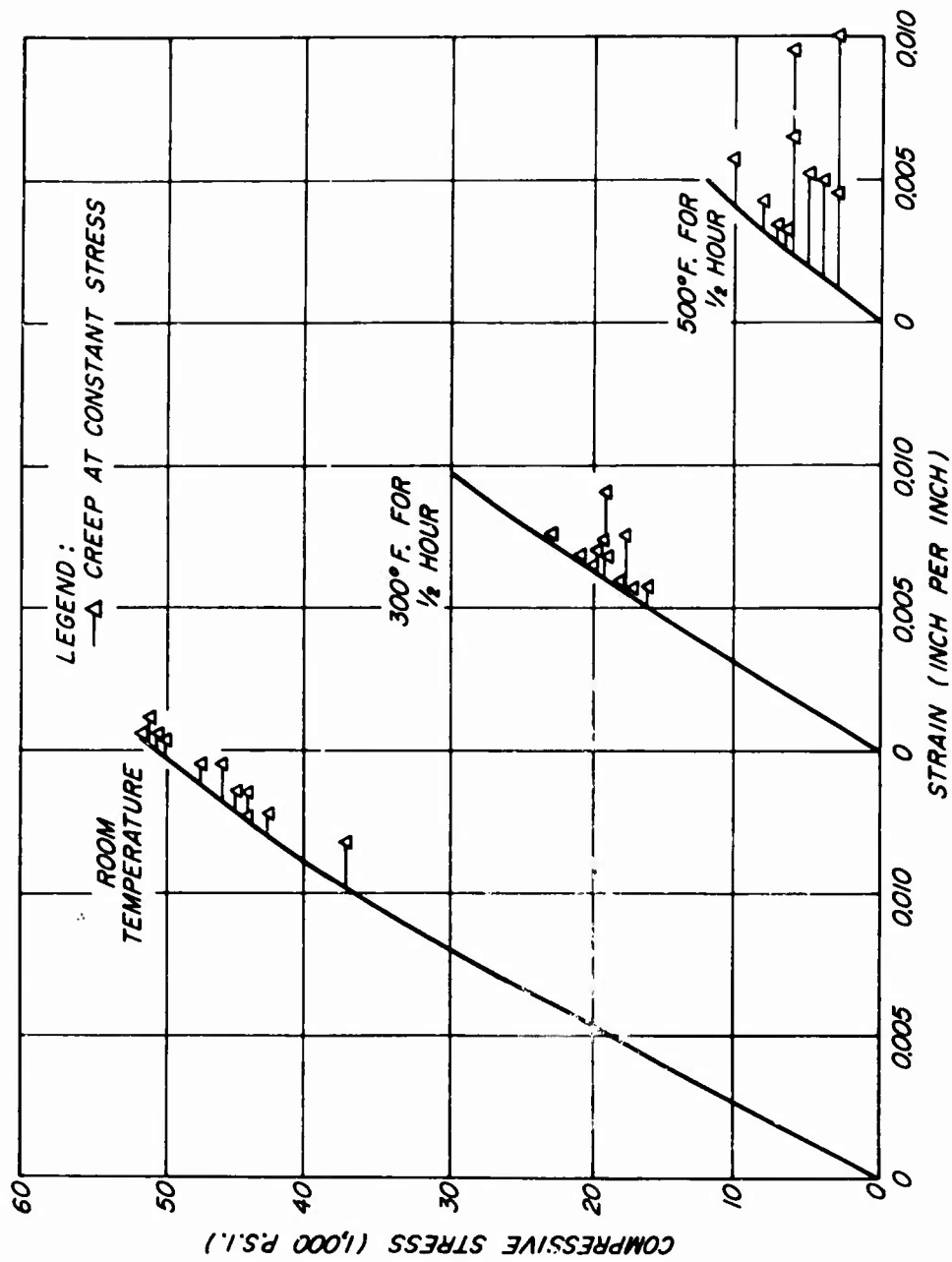


Figure 14.--Relationship of Compressive Creep at Various Stress Levels to Average Compressive Stress-Strain Curves for Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Class Fabric.

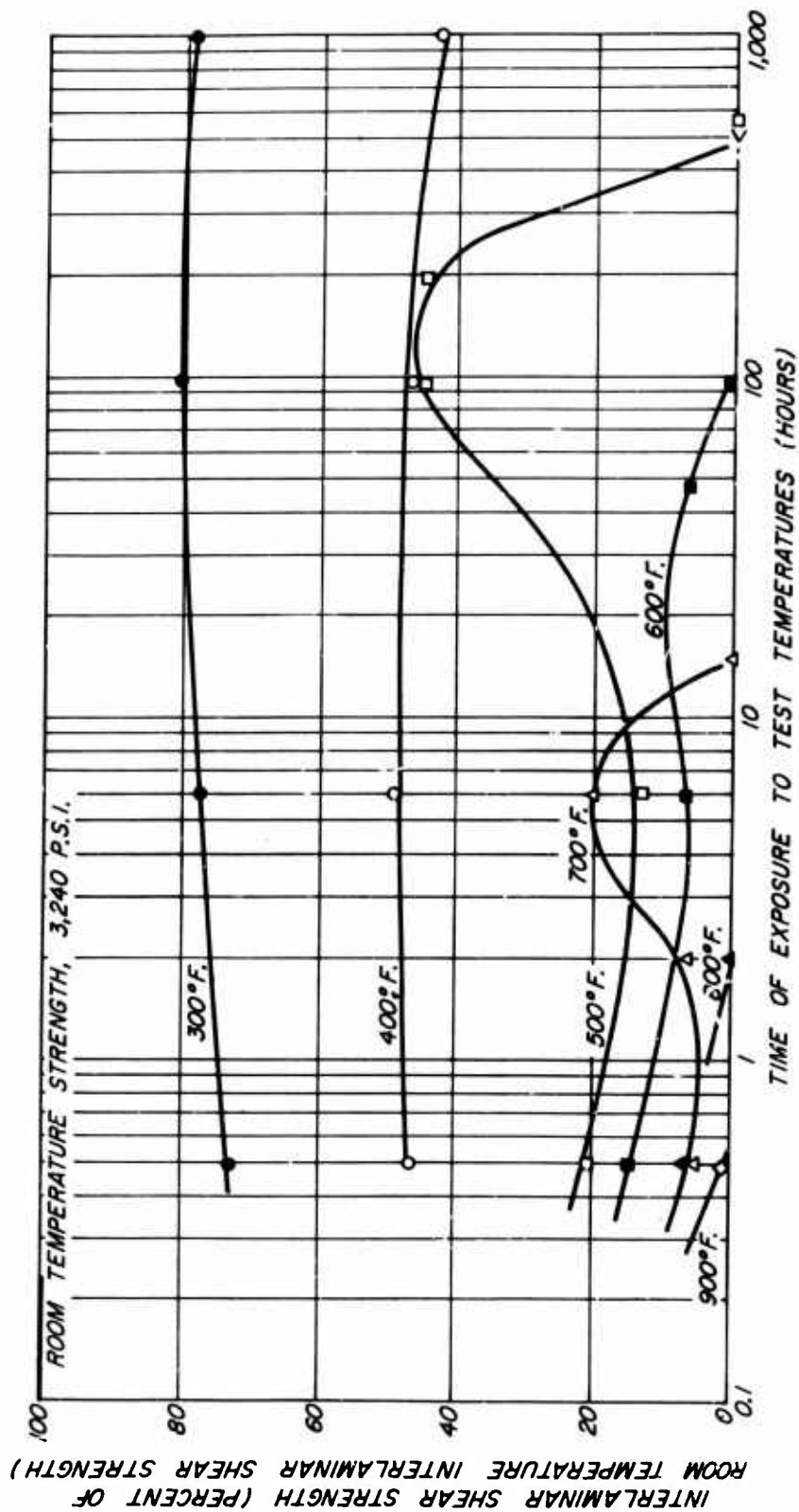


Figure 15. --Interlaminar Shear Strength at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

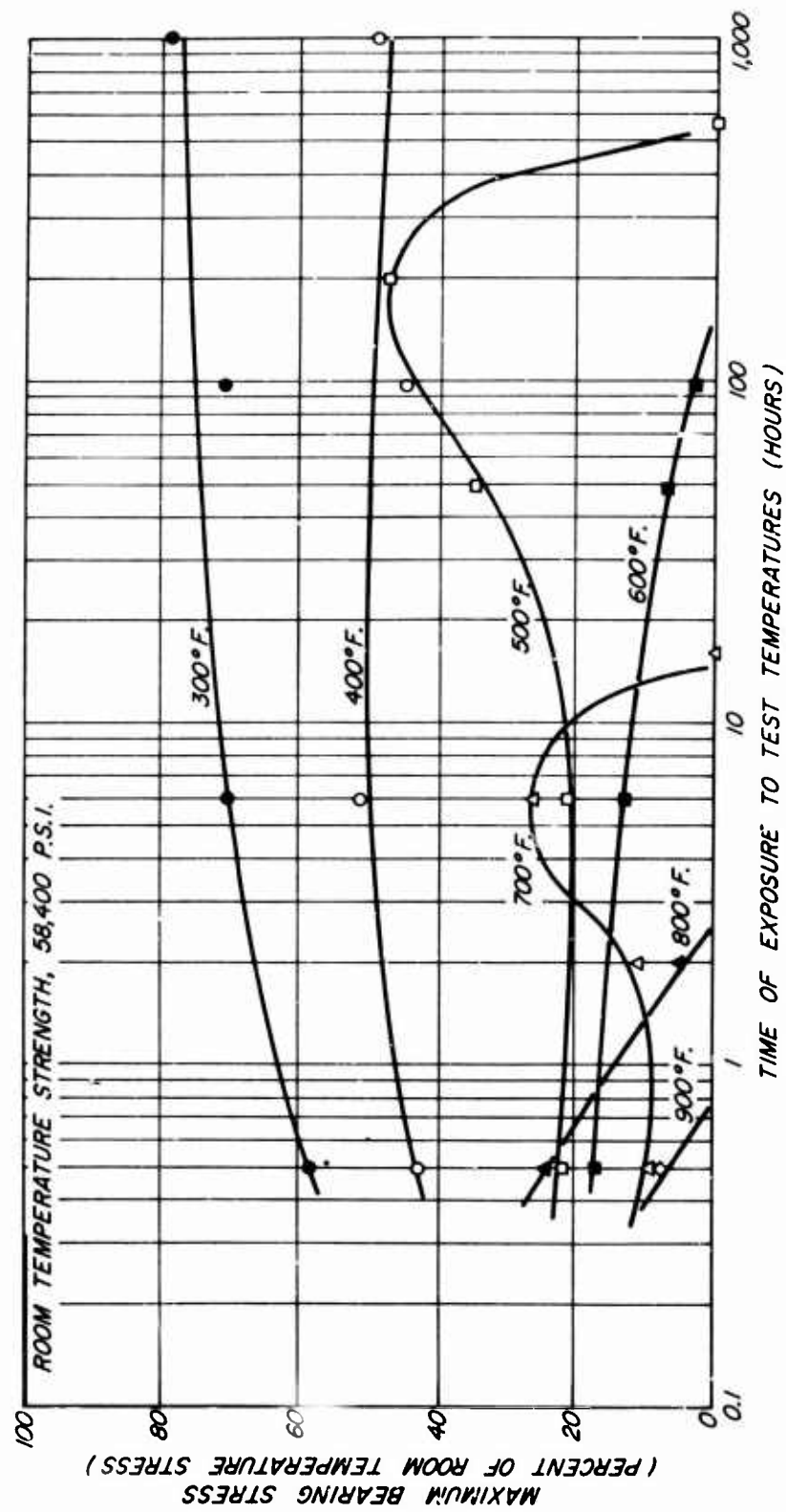


Figure 16. --Maximum Bearing Stress at Elevated Temperatures of Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

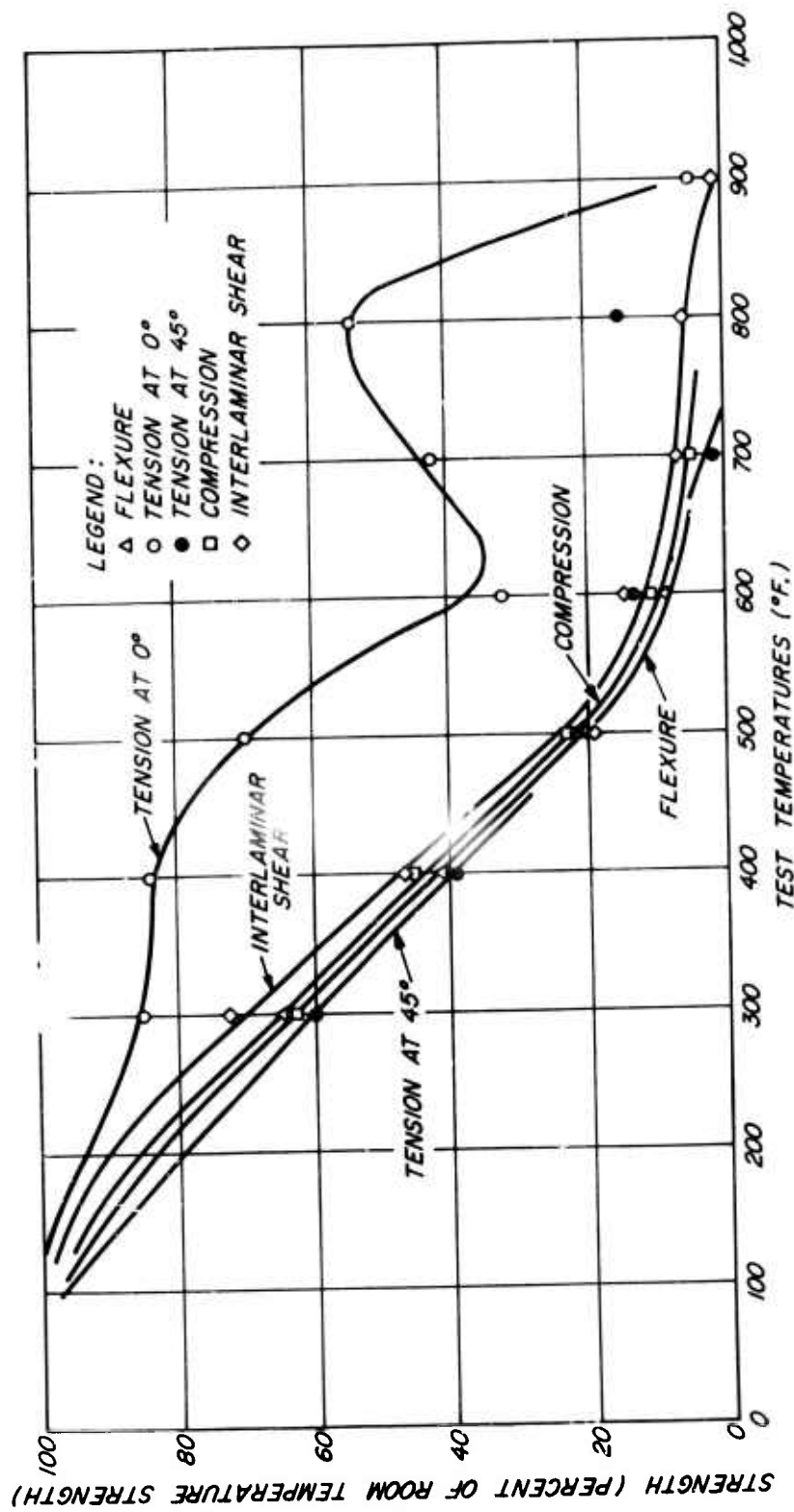


Figure 17.--Mechanical Strengths at Elevated Temperatures After 1/2-Hour Exposure for Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

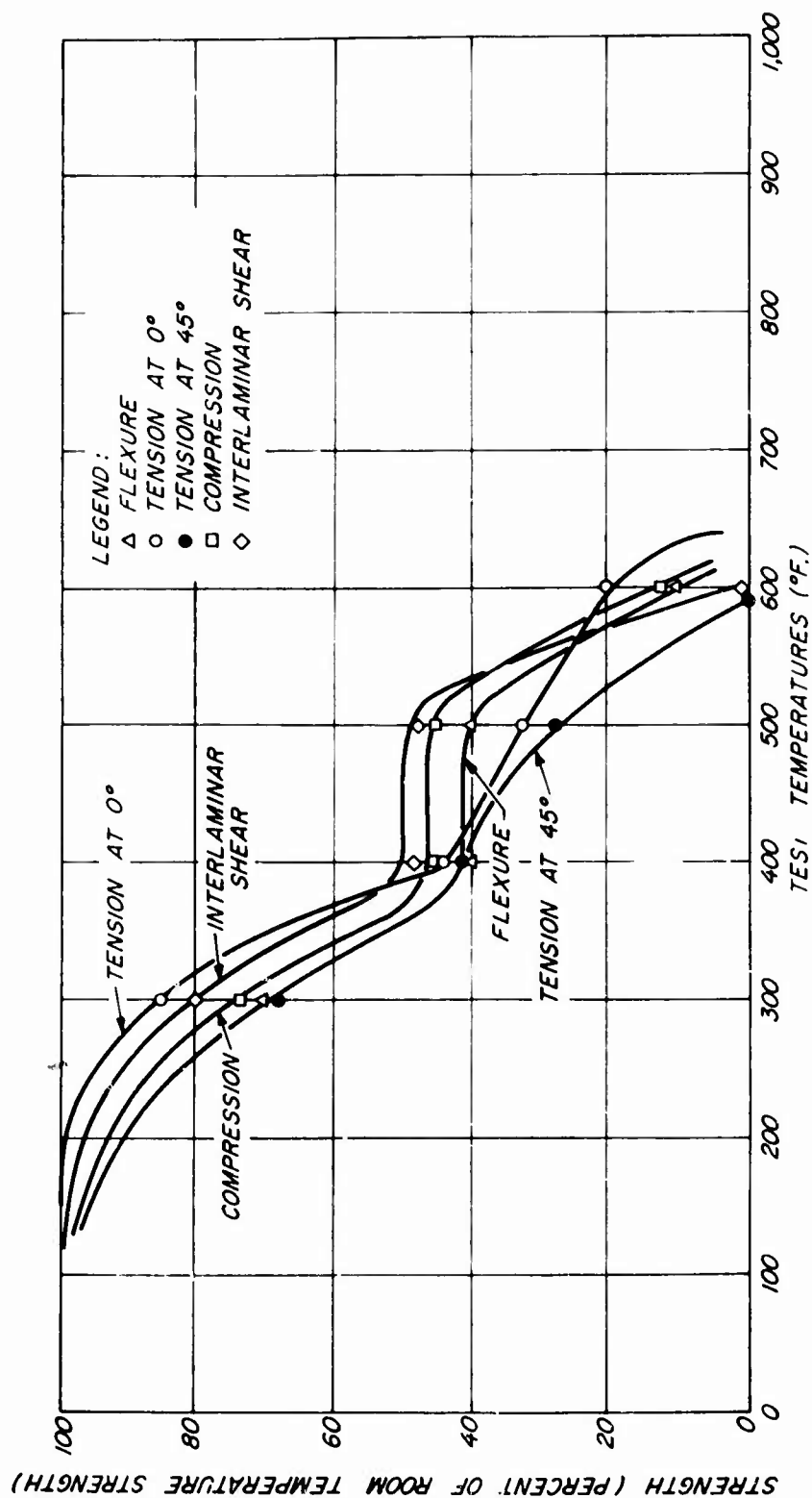


Figure 18.--Mechanical Strengths at Elevated Temperatures After 100-Hour Exposure for Epoxy Laminates Made of ERSB-0111 Resin and 181-S-HTS Glass Fabric.

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13. ABSTRACT <p>This report is one of a series that presents strength properties of materials designed to endure elevated temperatures. Strength properties and strength-exposure curves are given for an epoxy resin laminate, made by Union Carbide Plastics Company, with ERSB-0111 resin in conjunction with 181-S-HTS glass fabric. The data show the effects of temperature between 80° and 1,000° F., and exposure periods between 0.05 and 1,000 hours on the individual strength properties. The magnitude of the various effects may be judged separately. In general, the data show that all mechanical strengths, except tension at 0°, decrease uniformly with increases in temperatures of short duration. The tensile strength remained relatively high until a critical exposure was reached and then displayed erratic characteristics. Other mechanical strengths above 400° F. decreased with increased exposure but peaked at about 100 hours.</p>		

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